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EXPERIMENTAL EVALUATION OF PARTIAL REPELLENT TREATMENT FOR REDUCING BIRD DAMAGE TO CROPS

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SUMMARY

(1) In a 0·2-ha flight pen, flocks of twenty brown-headed cowbirds (*Molothrus ater* Boddaert) and twelve red-winged blackbirds (*Agelaius phoeniceus* L.) were observed as they foraged on plots sown with rice seed, 0%, 50% or 100% of which was treated with methiocarb.

(2) Seed removal by birds in plots with the 50% and 100% treatments was 95–98% less than that in the 0% groups. Seed handling behaviour did not differ among treatments for either species.

(3) These results are consistent with previous experimental findings and with theoretical models of automimicry that predict substantial protection to the entire prey population even when only a small proportion of the prey is unpalatable.

(4) Cost–benefit analysis suggests that partial repellent treatment for protection from bird damage, in addition to being environmentally sound, is economically viable in many crops.

INTRODUCTION

Reducing the amount of chemical repellent applied to a crop for bird-damage protection will result in a cheaper, more environmentally acceptable approach. Experiments with paired and singly caged house finches (*Carpodacus mexicanus* Müller) produced results (Avery 1985) consistent with theoretical models of automimetic systems (Brower, Brower & Corvino 1967; Brower, Pough & Meck 1970), suggesting that treatment of *c*. 50% of a crop with the repellent methiocarb (3, 5 dimethyl-4-(methylthio)phenyl methylcarbamate) is just as effective as treating the entire crop. Although encouraging, these results were obtained in caged foraging environments not resembling a field situation, and additional experiments were necessary to evaluate partial treatment as an alternative to total treatment. This paper reports the results of two sets of experiments conducted in a large flight pen using free-flying flocks of brown-headed cowbirds (*Molothrus ater* Boddaert) and red-winged blackbirds (*Agelaius phoeniceus* L.). The objective was to determine, under simulated field conditions, the effectiveness of partial treatment *v*. total treatment with methiocarb for reducing bird damage to sown rice.

METHODS

Experiments were conducted in a 0·2-ha flight pen at the Florida Field Station of the Denver Wildlife Research Center in Gainesville. Two 20×25 m ploughed areas in the flight pen were each divided into four 9×12 m experimental plots, each of which was assigned randomly to receive one of three treatments or to serve as an unsown, alternative feeding site. During a given trial, only the designated treatment plot and the alternate feeding site were exposed to bird pressure. At the start of each trial, 25–30 g of the birds' normal maintenance food (F-R-M® 15% Layer Crumbles) was scattered by hand over the alternative feeding site. The remainder of the ploughed area was covered with plastic covers. The arrangement of the plots was such that the separation between the alternative feeding site and the experimental treatment plot varied from 4 to 22 m throughout the study.

Three treatments were used: 0%, 50% and 100% treated seed. Methiocarb (0·125% by weight) was applied to the rice seed by adding the appropriate amount of chemical to a small quantity of water, and then mixing it with the seed in a rotating tumbler. Treated seed was air-dried for 24 h. Methiocarb was in the form of Mesurol® 75% Seed Treater (batch 4030163) supplied by Mobay Corporation, Kansas City, Missouri.

For each species, three separate groups of birds were tested in each treatment. Each test group consisted of either twenty adult brown-headed cowbirds (sexes combined) or twelve adult red-winged blackbirds (males only). All birds were trapped locally and had been in captivity for 2–8 months before testing. The cowbird trials were conducted first, and each lasted 4 days; because days 3 and 4 yielded no useful information that was not obtained on days 1 and 2, the redwing trials were reduced to 2 days' duration.

During the cowbird trials, five randomly placed 0·09 m^2 sampling quadrats, each initially containing fifty seeds, were used to estimate seed consumption. The sampling was increased to ten 0·19 m^2 quadrats for the redwing trials. To conserve seed, the sowing rate was reduced from 1·3 kg per plot in the cowbird trials to 650 g per plot for the redwings. The reduced sowing rate and larger sampling quadrats combined to maintain the number of seeds per quadrat at fifty. The seeds remaining on each quadrat were counted at 09.00 and 16.00 h on each day of the trial. Occasional heavy late afternoon and evening rain storms caused seeds to shift on the test plots and prevented accurate determination of seed removal between 16.00 and 07.00 h the next day. On the morning after such heavy rain, all quadrats were reset to fifty seeds.

Birds were observed from a blind for 1 h each morning and afternoon as they roosted and foraged in the flight pen. The birds foraged for insects and crumbled feed on the alternative plot and also fed extensively on wild grass seed. Feeding rates on rice seed were determined by watching birds through a 25 × spotting scope and recording the number of seeds picked up and the number eaten in 60-s periods. Observations of foraging birds were made haphazardly, not randomly.

The numbers of seeds removed by the birds from the sampling quadrats were analysed using the Kruskall–Wallis test (Langley 1971) to determine overall differences among treatments. Two specific comparisons were identified a priori for analysis: (a) seed removal from plots with 0% treated *v.* 100% treated rice seed and (b) seed removal from plots with 50% treated *v.* 100% treated rice seed.

Differences among treatments in seed handling rates by the birds and proportion of seeds eaten after handling were also analysed using the Kruskall–Wallis test.

RESULTS

Seed removal

Cowbirds removed 460 seeds from the 0% treated sample quadrats, compared with twenty-six and twenty-eight (94% reduction each) in the 50% and 100% treatment trials, respectively (Table 1). Similarly, seed removal by red-winged blackbirds during the three trials with the 0% treatment was 668 compared with twenty-six (96% reduction) and fifteen (98% reduction) in the 50% and 100% treatments, respectively. For each species,

TABLE 1. Number of seeds removed from sampling quadrats by bird flocks foraging for 2 days on plots containing rice seed, 0%, 50%, or 100% of which was treated with methiocarb

	Brown-headed cowbirds			Red-winged blackbirds		
	0%	50%	100%	0%	50%	100%
	126	4	12	113	11	4
	69	21	12	326	2	0
	265	1	4	229	13	10
$\bar{x}$(S.E.)	153 (58)	9 (6)	9 (3)	223 (62)	9 (3)	5 (3)

TABLE 2. Feeding responses of brown-headed cowbirds and red-winged blackbirds to rice seed, various percentages of which were treated with methiocarb

	Percentage of seeds treated		
	0	50	100
Mean (S.E) number of seeds eaten min^{-1}			
Cowbirds	4·4 (0·5)	2·3 (0·6)	4·6 (1·2)
Redwings	4·7 (0·4)	4·2 (1·0)	5·5 (0·8)
Mean proportion eaten of those sampled			
Cowbirds	0·79	0·49	0·73
Redwings	0·87	0·83	0·91

the 0% treatment differed significantly ($P < 0{\cdot}05$) from the 50% and 100% treatments, which were not different from each other ($P > 0{\cdot}10$).

Foraging behaviour

Observations during each group's initial encounter with the rice seed revealed no major differences between species or among treatments in feeding rate or in the proportion of seeds eaten that were handled (Table 2). Cowbirds in the 50% treatment groups had ($P < 0{\cdot}05$) lower feeding rates than those in the 0% groups, but the biological significance of this is unknown. The result may be an artefact of the small sample ($n = 6$).

Red-winged blackbirds in the 50% and 100% treatment groups foraged more extensively in the grass and alternative plot than those in the 0% groups (Fig. 1). Use of the alternative plot by the 0% groups was minimal and foraging in grassy areas by these groups was less than indicated because much of the birds' time was spent loafing, not foraging. Loafing time was not recorded separately from feeding activity.

DISCUSSION

From studies of mimicry in the monarch butterfly (*Danaus plexippus* L.), Brower, Pough & Meck (1970) predicted that, even at low model frequencies, substantial protection will be conferred on a prey population of models and visually identical mimics, especially if

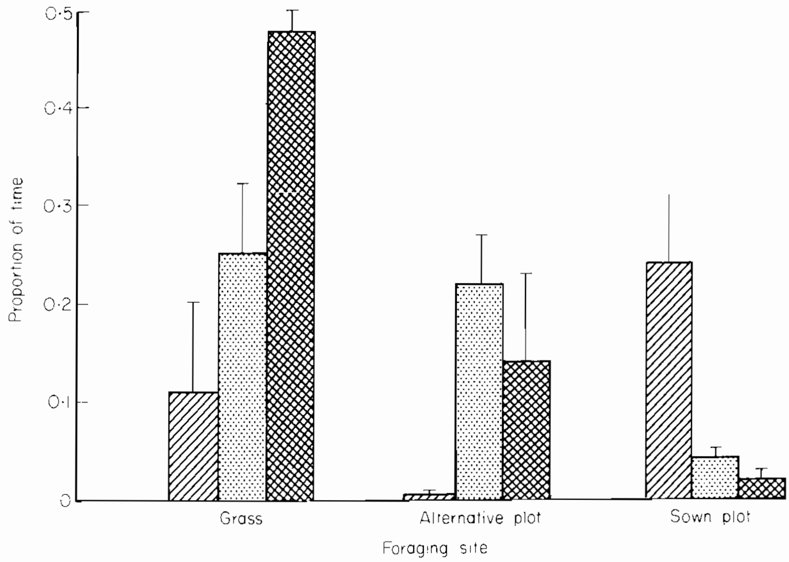

FIG. 1. Proportion of time red-winged blackbirds spent at different sites when the sown plot contained 0% (▨), 50% (▤), or 100% (▩) methiocarb-treated rice. (Capped vertical lines indicate one S.E.)

the models are highly noxious. Their mathematical treatment incorporated model frequency, degree of noxiousness and prey abundance. The results of the present study are consistent with the automimicry predictions (Brower, Pough & Meck 1970) and with results of previous laboratory experiments (Avery 1985). Thus, the partial treatment approach to crop protection with bird-repellent chemicals such as methiocarb seems to have a reliable ecological basis. To evaluate the economic aspects of this approach, a straightforward cost–benefit analysis was applied, similar to that of Dolbeer (1981).

The economic value of partial treatment depends upon the effectiveness and cost of the treatment and the value of the crop being protected. To be considered economical, the benefit of partial treatment must exceed that of total treatment. Net benefit is defined as the value of the entire crop (V) $\times$ the proportion successfully protected by the repellent treatment (p) minus the cost of treating the entire crop (C) $\times$ the proportion actually treated (m). Thus, if ($pV - mC$) for $m < 1$ is $\geqslant$ that for $m = 1$, it pays to adopt a partial treatment approach. In other words, if the savings from treating only part of the crop exceed the value of the crop lost to depredation, partial treatment is better. Algebraically, this can be derived as follows:

Partial treatment		Total treatment ($m = 1$)	
$p_1V - mC$	$\geqslant$	$p_2V - C$ or,	(1)
$C - mC$	$\geqslant$	$p_2V - p_1V$; rearranging terms gives	
C/V	$\geqslant$	$(p_2 - p_1)/(1 - m)$	(2)

where $(1 - m) = n$ is the proportion not treated, and $(p_2 - p_1) = d$ is the difference between the proportion of the crop protected by total (p_2) and by partial (p_1) treatment. Substituting into eqn (2) and rearranging gives

$$Cn \geqslant dV. \tag{3}$$

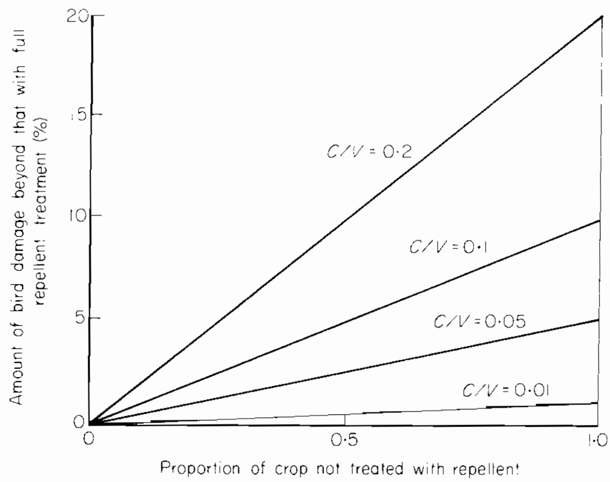

FIG. 2. Maximum acceptable bird damage beyond that incurred with full treatment for which partial repellent treatment will be cost-effective. (C/V = cost of full repellent treatment/value of fully treated crop).

TABLE 3. Maximum acceptable additional crop loss beyond that incurred with full methiocarb treatment, assuming a partial treatment rate of 50%

Crop	C/V*	Maximum additional crop loss beyond that with full treatment (%)	Reference
Sown maize	0·008	0·4	Heisterberg (1983)
Cherry	0·017	0·9	Porter (1982)
	0·022	1·1	Tobin & Dolbeer (1987)
Wild rice	0·076	3·8	Gorenzel, Marcum & Salmon (1986)
Sown rice	0·215	10·8	Holler *et al.* (1982)

* Cost of full repellent application/value of fully protected crop.

Cn represents the money saved by not treating the entire crop, and dV is the incremental economic loss resulting from partial treatment.

By examining eqn (3) in more detail, it is possible to determine the conditions under which partial treatment is a viable approach. First, it is not reasonable to expect complete protection from total treatment. Holler *et al.* (1985) recorded 7·1% loss of sprouting rice in fields treated with methiocarb. Moulton (1979) found losses of 12·5–32·5% in wild rice aerially sprayed with methiocarb. In methiocarb-treated cherry orchards, losses of 7·1% (Porter 1982) and 8·9% (Tobin & Dolbeer 1987) have been reported. Thus, in evaluating the economic benefit of partial repellent treatment, the standard for comparison must be the amount of crop loss with total treatment, which is not necessarily 0%. What then is an acceptable incremental crop loss, d?

Even when the cost of repellent treatment is high relative to the value of the crop, d must be quite small for partial treatment to be feasible (Fig. 2). For example, when $C/V = 0{\cdot}1$, treatment of half the crop ($n = 0{\cdot}5$) must result in no more than a 5% loss above that for total treatment, in order to be economically viable. As C/V decreases to 0·01, the maximum acceptable loss increment becomes 0·5%, when half the crop is not treated. Information on the cost of repellent treatment and the value of the crop is not available for many crops, but the published data indicate a broad range of C/V (Table 3). As the cost of repellent application relative to crop value decreases, so does the magnitude of the economic benefit of partial treatment. For very high-value crops, the cost of repellent treatment may be inconsequential and there may be no economic incentive for partial treatment.

However, in addition to economic considerations, the environmental consequences of partial repellent treatments are also important because the risk of affecting non-target organisms is lessened. For instance, although methiocarb applied at registered rates is not hazardous to birds, it is toxic to invertebrates and some aquatic vertebrates (Smith 1987). By partially treating, the risk to such sensitive organisms is substantially reduced and, using the appropriate treatment level, the grower is not penalized economically. Methiocarb is not, at present, registered as a bird repellent in the U.K. and its status as a registered bird repellent in the U.S.A. is in jeopardy (Tobin & Dolbeer 1987). The use of partial treatment and the consequent reduction in non-target hazards may increase the likelihood of methiocarb and similar repellents being registered for use by regulatory agencies. Conceivably, the partial treatment use could be included in the label restrictions for such compounds.

The concept of applying chemical bird repellents, such as methiocarb, in a partial treatment design has solid support from experimental evidence and ecological theory, and it makes sense economically and environmentally. However, field studies testing the efficacy of partial treatment have not been performed. Furthermore, the effectiveness of the approach will probably differ among crops. Partial treatment will be most effective in protecting sown crops such as rice and maize, where treated and untreated food items are mixed together throughout the field. In fruit crops, it is not possible to treat individual fruits, but it may be feasible to spray individual trees or parts thereof. The resulting clumps of treated and untreated food items should provide some protection (Avery 1985), but are not expected to be as effective as the randomly distributed individually treated food items (Porter 1977).

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